A Closing, High-speed Plankton Catcher for Use in Vertical and Horizontal Towing

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A FEATURE common to conventional conical nets is the speed at which they may be towed —one to two or three knots (1 kt. equals 1.85 km./hr.)—which is necessary to safe working of the gear and an undamaged condition of the catch. Increasing the speed of towing is believed to set up a zone of pressure which advances before the mouth of the net, possibly warning or otherwise causing animals to avoid capture.

Modifications in attempts to improve the efficiency of this basic type of net, include methods of opening and closing nets under water (Kemp, Hardy and Mackintosh, 1929; Marr, 1938; Barnes, 1953; Currie and Foxton, 1957); alteration of its shape, as in the Hensen and Apstein nets (Sverdrup, Johnson and Fleming, 1942), and as made by Sheard (1941), and Barnes (1953); addition of flow meters to determine the volume of water filtered (Harvey, 1934; Clarke and Bumpus, 1940; Arnold, 1952; Currie and Foxton, 1957); and means of taking series of discrete samples (Hart, 1935; Motoda, 1952).

A different approach involves the type of sampler which can be towed horizontally at higher speeds. The mouth in this type usually precedes the towing point (unlike conical nets) so that the sample is collected from undisturbed water; when combined with high speed through the water, this contributes towards collecting a wide range of organisms.

In general, high-speed catchers incorporate a type of conical net, either in a rigid frame (Cassie, 1956), or in a rigid (metal) container (Arnold, 1952; Gehringer, 1952). Usually the area of the mouth is much restricted relative to the area available to filtering the water, but in the Gulf Sampler III (Gehringer, 1952) the diameter of the mouth (16 inches) is almost that of the contained net. Flow meters may be incorporated as in the tail of the Scripps High Speed Sampler (together with a depth recorder); in the Gulf Sampler IA (Arnold, 1952); and in mouth and tail of the Gulf Sampler III (Gehringer, 1952). To the best of our knowledge, no high-speed sampler can be closed when towing is completed.

The Continuous Plankton Recorder (Hardy, 1935) operates on the principle of a continually renewed filtering area, and, although it is a high-speed sampler, is in a different category from those already discussed.

Less attention has been paid to more rapid sampling by vertical tows. In one method (Hart, 1935) flights of small, conical nets are evenly spaced on a wire and are towed over a vertical distance equivalent to the spacing; they are then closed and hauled in. Samples are thus collected simultaneously from several levels. Motoda (1952) incorporates a series of collecting buckets in a frame; unused buckets successively lock on to the cod end of the net during a step-by-step rotation of the frame. Each bucket collects material only over a particular range of depth. None of this style of nets is towed faster than about one metre per second (two knots).

Nets for vertical towing are usually constructed somewhat differently from those for horizontal or oblique tows (Kemp, Hardy, and Mackintosh, 1929). To convert from the one use to the other may be impracticable,

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thus making various sorts of nets almost obligatory. Material thus collected could be compared only with difficulty (e.g., see Winsor and Walford, 1936; Winsor and Clarke, 1940; Barnes and Marshall, 1951). More important, perhaps, is the limitation a multiplicity of gear imposes on assessment of relative efficiencies of vertical and horizontal tows as methods of quantitatively sampling a water column.

The following account is of a plankton catcher designed for both vertical and horizontal sampling, and requiring a minimum of conversion from the rigging for one type of tow to that for the other. Its rigid outer casing is of fibreglass; it has a comparatively wide mouth, contains a conical net of stainless steel, and has been towed successfully at speeds up to 10 kt. horizontally, and 5 to 6 kt. vertically. A valve, which can be closed by a messenger, stops the flow of water into the net, and there is a depth-flow meter in the tail. The diameters of mouth and valve differ, and it is the narrower aperture of the valve that controls the flow into the catcher. It accepts 89 per cent of a column of water, of an equivalent area of cross section, at speeds between 3 and 10 kt. The result encourages us to publish details of the catcher and its performance. The principles of its construction appear sound, but some modifications are being considered in plans for a second instrument.

REQUIREMENTS FOR THE CATCHER

The requirements on which the design of the catcher was based are:

1. That collections made may be profitably subjected to quantitative analysis.
2. That speeds of 6 kt. or faster, both vertically and horizontally, may be achieved.
3. That more than one unit may be attached to a single, vertical wire.
4. That no encumbrances precede the mouth during either vertical or horizontal towing.
5. That it be versatile in catching power.

To be a "quantitative" sampler, the mouth must be closable during vertical and horizontal towing. Second, the volume of water passing through the filter must be measured. Third, development of a pressure zone preceding the mouth must be minimised by making flow through and around the catcher of low impedance.

A low resistance to flow inside the catcher, together with a long streamlined body, contributes towards fast stable towing with least drag. During vertical towing the unit is attached by its side to a weighted wire, and its ability to tow in a stable manner is relied on to reduce the angle at which it hangs (on the vertical wire). Excessive drag would act to increase the angle. The inherent stability also ensures steady true towing at the higher speeds in a horizontal direction.

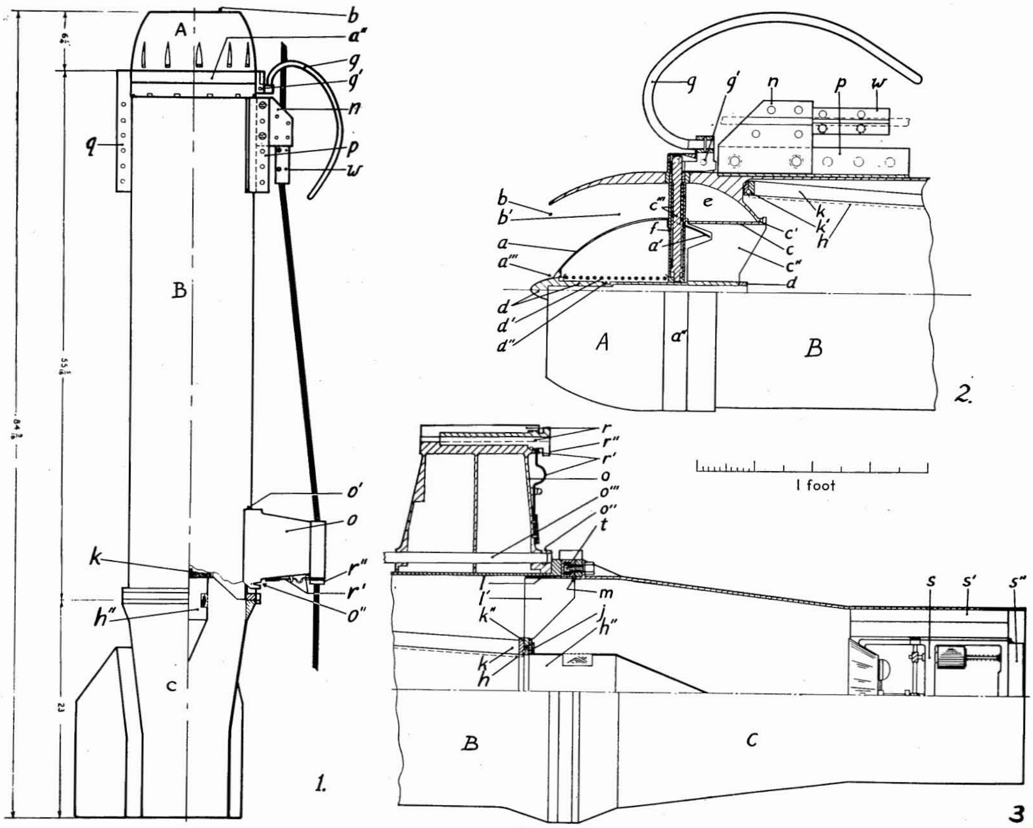
In horizontal tows hauling from a point behind the mouth eliminates bridles, and other attachments, preceding the mouth. The advance of such attachments possibly warns or scares at least the more agile zooplankton. In vertical tows, the wire is to one side of the mouth. It may possibly become a relatively constant feature and therefore not be so disturbing to organisms. The mouth remains otherwise unobstructed.

Fast towing, both vertically and horizontally, and the wide unobstructed mouth are aimed at providing collections which are widely representative of the organisms encountered in a column of water.

DESIGN AND CONSTRUCTION

In Figures 1, 2, and 3 the construction and relationships of parts of the catcher are shown; Figure 4 is a photograph of the dismantled catcher, and Table 1 is a schedule of parts.

The outer shell is rigid, 7 feet long, and can be dismantled into three major sections, nose-, body-, and tail-pieces (Figs. 1 and 4, A, B, C). The nose incorporates the opening of the mouth and the closing mechanism, the body contains the conical net, and the tail the depth-flow meter and stabilizing fins. Normally the nose is bolted to the body, but the



FIGS. 1–3. (1) General diagram of catcher, rigged as for vertical towing.
(2) Nosepiece, mouth chamber, and valve chamber showing the relationships of the parts to each other, to the forward end of the body and the net. Note that the valve is closed.
(3) Tailpiece showing the after end of the net, its frame, the depth-flow meter and the vertical-wire bracket.
Note: Figures 2 and 3 are to same scale and are × 2, Figure 1; for legends, see Table 1.

tail is removable and the net then can be freely withdrawn towards the rear.

Nose, body, and tail (including the fins) are manufactured from Crystic 191, an epoxy resin, with fibreglass reinforcement. These materials have important advantages. Together, they are tough, light in weight (specific gravity 1.3 approx.) and non-corrodible in seawater. Absorption of water is very low and they have proven dimensionally stable in the catcher under diverse conditions of towing and handling. They have been subjected to pressure at 1500 m. without any indication of delaminating or pulverizing in spite of small entrapped bubbles of air.

The opening of the mouth is 9 in. in diameter and leads into the mouth chamber (Figs. 1, 2, 4, *b*). Behind, and partly contained by the nosepiece, is a separate valve chamber (2, *e*). Castings forming the mouth and valve chambers are mounted on a cast bronze ring (Figs. 1, 2, 4, *a''*). The internal surfaces of the chambers and ring are continuous, and they curve inwardly towards the rear, where they form a circular opening of 7½ in. diameter. The inner surface of this acts as a bearer to the outer face of the valve (2, 4, *c'*).

The valve (Figs. 2, 4, *c*) is a short, open-ended cylinder, of 7¼ in. internal diameter.

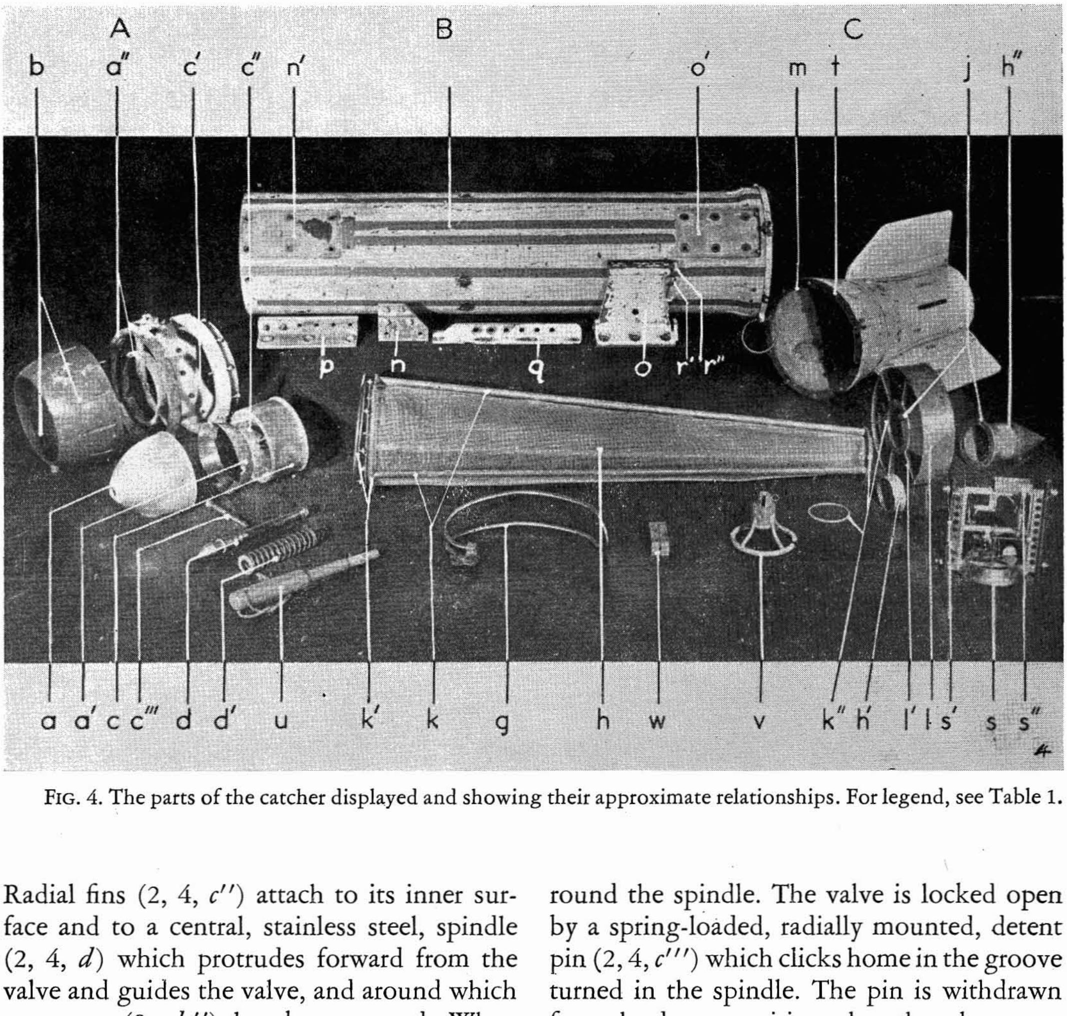


FIG. 4. The parts of the catcher displayed and showing their approximate relationships. For legend, see Table 1.

Radial fins (2, 4, *c''*) attach to its inner surface and to a central, stainless steel, spindle (2, 4, *d*) which protrudes forward from the valve and guides the valve, and around which a groove (2, *d''*) has been turned. When closed, the leading edge of the valve abuts against the trailing edge of a streamlined boss (2, 4, *a*), set in the mouth, and the forward end of the spindle closes a hole of 1 5/16 in. diameter (2, *a'''*) in the front of the boss. A faring (2, 4, *a'*) extends rearward from the boss to improve streamlining. Four holes, 3/16 in. diameter, pierce the front end of the boss. When the unit is raised from the water, air enters by these and enables entrapped water to escape freely.

The valve is opened by pushing the spindle towards the rear with a thruster or loader (4, *u*) through the hole in the boss. This compresses a coiled spring (2, 4, *d'*), fitting round the spindle. The valve is locked open by a spring-loaded, radially mounted, detent pin (2, 4, *c'''*) which clicks home in the groove turned in the spindle. The pin is withdrawn from the detent position when the release arm (1, 2, 4, *g*) is actuated by the weight of a messenger (4, *v*; 6, 7). The spring-loaded spindle is thus released and moves the attached valve rapidly forward, shutting off the flow of water to the net.

The filtering net (Figs. 2, 3, 4, *h*) is of stainless steel mesh; joints are folded, spot welded and then sealed with "Araldite." The ratio of the total area of the filtering holes and the valve (see below) of the catcher is approximately 11 for a net of 40 meshes to the inch and 14 for a net of 10 meshes to the inch. A frame encloses the net. It consists of three tubular brass struts (1, 2, 3, 4, *k*) attached to a forward clamp ring (2, 4, *k'*),

TABLE 1

LIST OF PARTS OF CATCHER, DESIGNATED IN FIGURES 1 TO 4

SECTION	DESIGNATION	PART	FIGURES IN WHICH PART IS PRESENT			
			1	2	3	4
Nosepiece.......	A		x	x		x
	a	Boss....................................		x		x
	a'	Boss, after faring of.........................		x		x
	a''	Boss, supporting ring (Bronze)..............	x	x		x
	a'''	Boss, forward hole in........................		x		
	b	Mouth....................................	x	x		x
	b'	Mouth, chamber...........................		x		
	c	Valve....................................		x		x
	c'	Valve, bearing surface for....................		x		x
	c''	Valve, radial supporting fins..................		x		x
	c'''	Valve, detent pin and spring..................		x		x
	e	Valve, chamber............................		x		
	d	Spindle to valve...........................		x		x
	d'	Spindle, coiled closing spring.................		x		x
	d''	Spindle, groove for detent pin................		x		
	f	Housing for detent pin and spring...........		x		
Bodypiece.......	B		x	x	x	x
	g	Closing mechanism release arm..............	x	x		x
	g'	Closing mechanism release arm, attachment point................................	x	x		
	h	Net, (Stainless steel).......................		x	x	x
	h'	Net, stretcher ring for cod end...............				x
	h''	Net, plankton bucket.......................	x		x	x
	j	Locking studs for bucket....................			x	x
	k	Net frame, (struts of)......................	x	x	x	x
	k'	Net frame, forward clamp rings..............		x		x
	k''	Net frame, after clamp rings..................			x	x
	l	Net frame, thrust ring......................			x	x
	l'	Net frame, radial fins between thrust ring and struts..............................			x	x
	m	Thrust surface of tail.......................			x	x
	—	Towing brackets..........................	x	x	x	x
	n	Towing, vertical, forward..	x	x		x
	n'	Towing, vertical, attachment area...........				x
	o	After, vertical bracket.....................	x		x	x
	o'	After, vertical, attachment area.............				x
	o''	After remote messenger release point........	x		x	
	o'''	After remote messenger release rod..........			x	
	p	Horizontal towing bracket.................	x	x		x
	q	Depressor bracket.........................	x			x
	—	After bracket, wire-catch....................	x		x	x
	r	Wire-catch, slot for wire....................			x	
	r'	Wire-catch, locking catch and spring..........	x		x	x
	r''	Wire-catch, rotating central spindle...........	x		x	x
Tailpiece........	C		x		x	x
	s	Depth-flow meter.........................			x	x
	s'	Depth-flow meter, runner mounting...........			x	x
	s''	Depth-flow meter, revolution counter..........			x	x
	t	Locking studs of tail.......................			x	x
Miscellaneous...	u	Loader...................................				x
	v	Messenger................................				x
	w	Wire stop.................................	x	x		x

which holds the upstream end of the net to the frame. At the rear the struts attach to a flange (3, 4, *k''*) which fits snugly about the cod end of the net. The cod end, in turn, is forced against the flange by a conically shaped stretcher ring (4, *h'*), fitted internally. Radial fins (3, 4, *l'*) extend outward from the flange to a deep thrust ring (3, 4, *l*). When the frame and net are inserted into the body from the rear, the thrust ring locates the after end (Fig. 3), and the clamp ring locates the forward end (Fig. 2). The forward end of the tail has an internal diameter 3/16 in. less than the after end of the body. When the tail is on, an internal lip is formed (3, 4, *m*) which abuts against the rear edge of the thrust ring, and provides a thrust surface. The assembly serves to push the net from the downflow end into the water entering through the valve. On removing the tail the frame is retained by a spring clip which is attached to the thrust ring, and which engages with the body. The tail is locked onto the body by a simple, external catch after a part turn has been made over locking studs (3, 4, *t*). The plankton bucket (1, 3, 4, *h''*) is removed after releasing a clip and also making a part turn over locking studs (3, 4, *j*). Its rear end is streamlined where it extends back into the tail piece.

The depth-flow meter (Currie and Foxton, 1957) is fastened in the tail on two runners (Figs. 3, 4, *s*, *s'*). It can be slid rearwards, clear of the end of the tail, to facilitate its being handled and read. The impellors turn only with forward motion of the catcher and rotate a drum on which a smoked glass cylinder is slipped. We have modified the meter so that the drum in turn drives a dial-type revolution counter (3, 4, *s''*). A Bourdon pressure unit is attached to a pen and, on reduction of pressure, causes a longitudinal trace to be made on the smoked cylinder. During a vertical tow, this is combined with rotation of the cylinder, when a helical trace results, from which depth and flow can be obtained. In a horizontal tow, the revolution counter gives the number of turns made by the cylinder while the trace on its surface gives the depth to which the catcher was lowered, and at which it was towed. The amount of water which passes through the net during the period of lowering is also indicated.

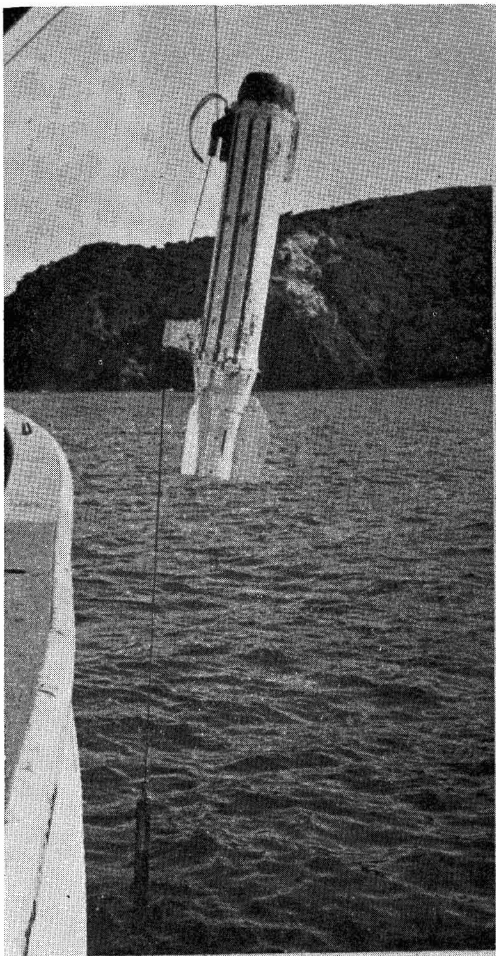
The weight of the catcher is 120 pounds (54.5 kilos) when rigged for horizontal towing, and 130 pounds (59 kilos) for vertical towing. To these must be added, respectively, 45 pounds (20 kilos) for a depressor (Fig. 7), and 45 pounds for a lead sinker (Fig. 5).

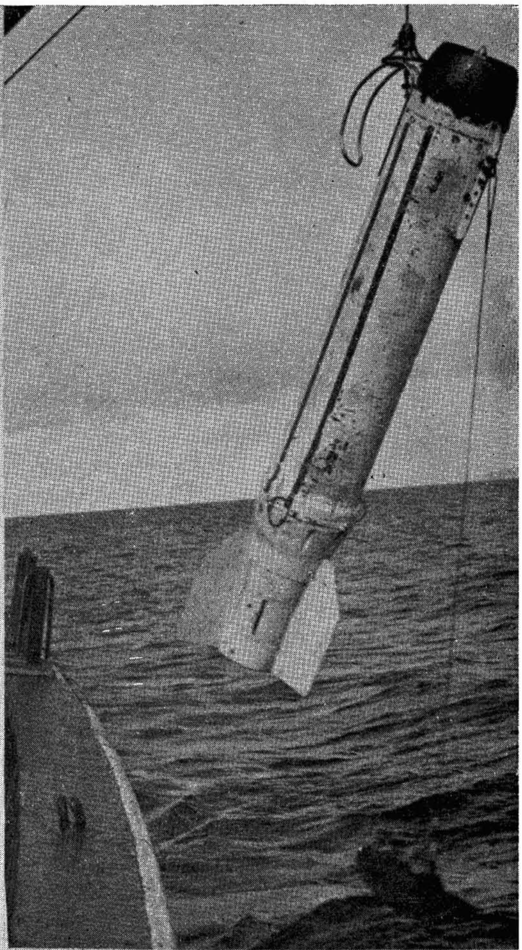
TOWING ATTACHMENTS AND RELEASE ARM

Vertical Towing

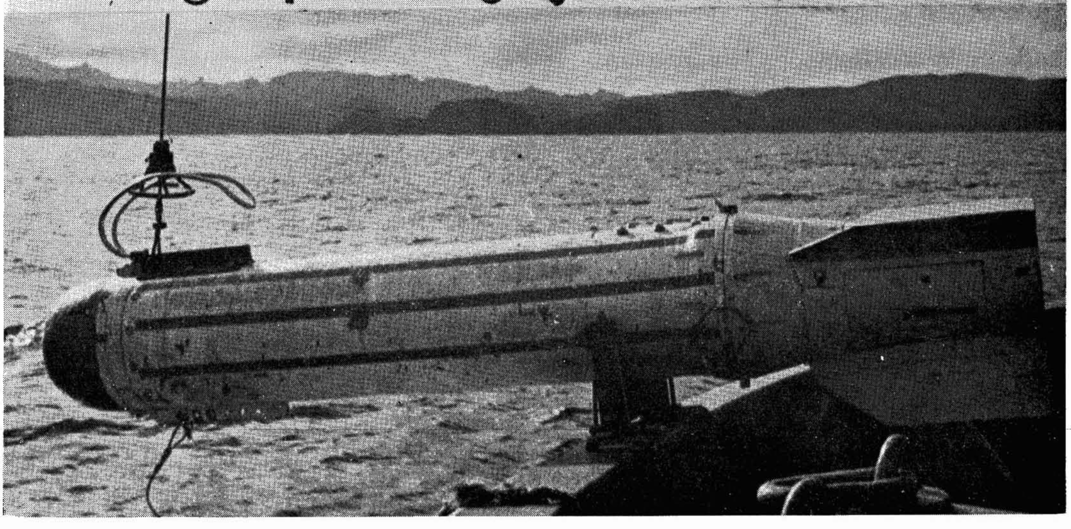
Vertical towing requires forward and after brackets for attaching the wire to the catcher (Figs. 1, 2, 4, *n*, *n'*, and *o*, *o'*). The catcher is supported by the forward bracket on a stop (1, 2, 4, *w*) on the wire; the after bracket is a spacer. Free rotation about the wire is allowed. The wire is inserted via a slot (3, *r*) into a central rotating portion (1, 3, 4, *r''*), which turns through 180° and is locked in place by a spring clip (1, 3, 4, *r'*). Initially forward and after brackets were similar. Each held the wire about 7 in. off the side of the catcher, but this method introduced many difficulties and had to be abandoned. In the method now employed the after bracket remains, but the forward bracket (a temporary one, see Figs. 1, 2, 4, *n*) offsets the wire by only 3 in. It is inserted in, and attached to, the horizontal towing bracket (1, 2, 4, *p*) which has a **U**-shaped section. Underwater observations indicate that at a vertical towing speed of 2 to 3 kt. the catcher is at an angle of about 5°, but as the speed is increased to 6 kt. the angle progressively decreases until for all practical purposes, the unit tows in a vertical position.

The heavy sinker (45 pounds, Fig. 5) is not necessary when towing vertically, but is essential during rapid lowering to reduce a tendency in the catcher to dive nose first. As the valve is open, the catcher would be fishing





5 ↑ 6 ↓ 7 ↑



and the flow-meter registering were this permitted.

To facilitate using flights of catchers on a vertical wire, a mechanism for releasing a messenger from the after end of each catcher was constructed. The impact of the messenger on the release arm set free the lower messenger which, in turn, triggered the closing mechanism of the next catcher down the wire, and so on. Part of the mechanism was in the rear bracket and is shown in Figure 3, *o''*, *o'''*; some of it was also built into the original forward bracket, but this has not been continued in the present one. The assembly has now been dismantled, but there are few difficulties to its reintroduction.

Horizontal Towing

To convert from the rigging for vertical, to that for horizontal tows, takes about five minutes. The wire stop, and the after and forward brackets are removed. The eye of the towrope is inserted into the bracket (Figs. 1, 2, 4, *p*) used for horizontal tows, at a point close behind the attachment of the release arm of the closing mechanism (1, 2, *g'*).

Because the catcher is required to be towed at depth, a 45-pound depressor (as supplied by Scripps Institution of Oceanography) is attached (Fig. 7). It hangs on a free wire from a bracket on the underside of the forward end (1, 4, *q*). It is most efficient, but in rough weather it is difficult to handle, and causes further trouble when it snatches into passing waves. A removable, adjustable, built-in depressor would be desirable in a future model.

The Release Arm (Closing Mechanism)

The same release arm (Figs. 1, 2, 4, *g*; 5, 6, 7), of stainless steel tubing, operates the closing mechanism in vertical and horizontal towing. It is essential that the surface which the messenger strikes is approximately at right angles to the run of the wire. Provision for this is made in the curvature of the arm. The messenger (4, *v*; 6, 7) carries a ring on a frame from its base, so that the two sides of the arm are struck, wherever the wire is located between them.

Features which are novel to the plankton catcher are its fibreglass construction, the sleeve-type valve for stopping the flow of water into the net, and the readiness with which conversion from a catcher for vertical towing to one for horizontal towing is carried out (without alteration of the catching power).

EFFICIENCY TRIALS

Trials to determine the efficiency with which the catcher accepts the water presented to it, and the effects that nets may have, have been carried out. The course and nature of the flow through the mouth and valve are indicated by tests with a two-dimensional model.

Model Tests

The model of the mouth and valve is a full-scale longitudinal, sagittal section, one-half inch thick, which is sandwiched between sheets of "Perspex," screwed to the model and to separating pieces at the sides. A diffuser placed between inlet ports and model ensures that parallel lines of flow are presented to the model. Flow lines were indicated by cotton threads attached to a small metal sledge (made in the form of a box, but open to the flow at the sides) which was manoeuvred about the model with a magnet. The width of the test channel is 18 inches by one-half

FIGS. 5–7. (5) The catcher before lowering for a vertical haul. The lead sinker just clears the surface of the water. (The dark stripes on the body are "Scotchlite" fluorescent tapes which assist during subsurface observations.)

(6) The catcher, rigged for horizontal towing, hanging in the guardrail crotch. The nose-down position, as illustrated, is a steady one when moving between stations. Until the net is withdrawn, however, the nose is kept higher than the tail.

(7) The catcher as recovered from a horizontal tow. It is closed, as shown by the head of the spindle protruding from the mouth; a messenger rests on the release arm of the closing mechanism. The depressor hangs below the catcher.

inch, of which the mouth intercepts 9 in. The remaining 9 in. is divided between the channels lateral to the model. Each of these narrows from 4½ in. to 2½ in.

Figure 8 is a composite drawing and shows the flow lines at an estimated 4 kt. (left half) and 1 to 2 kt. (right half). A positive pressure gradient builds up lateral to the model, as a result of the restriction to flow due to the narrowing of the channels, and is probably responsible for the inwardly sloping flow lines at, and preceding, the leading edge of the mouth. There is a similar, but stronger, inflow towards the hole in the front of the boss. A positive pressure gradient again would seem to be the cause, but arising in the nature of the flow around the boss, and along the channels of mouth and valve chambers. The effects of the gradients become more evident at the faster rate of flow. It is possible that the representation of the flow lines preceding the leading edges of the mouth of the model are not what would obtain in open water with the catcher. However, flow lines into the hole in the boss are distorted by pressure developing as a result of the design of the mouth and valve chambers, and in this case the effect would probably also occur with the catcher. Should either gradient persist during towing, a zone of higher pressure would precede the mouth. This feature is undesirable, although the end result may well be to reduce the actual mouth area to an effective one more nearly equivalent to the area of the orifice controlling the flow into the catcher, namely the valve (see later).

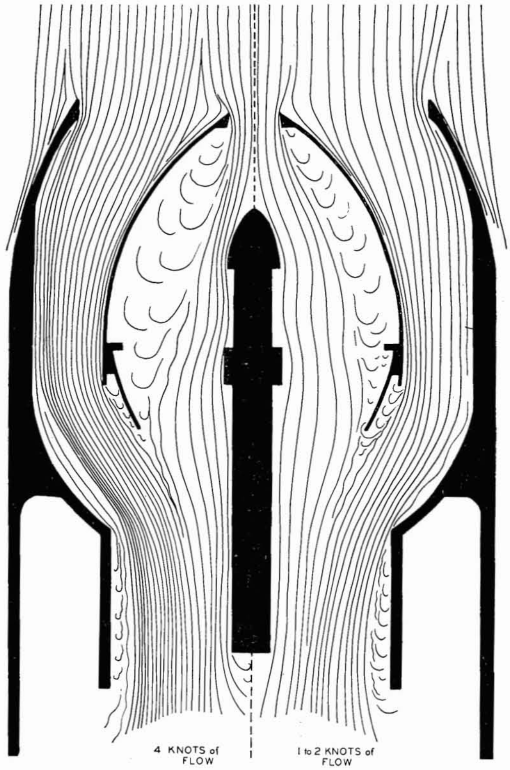


FIG. 8. Composite drawing showing flow lines for estimated speeds of 4 kt. (left half) and 1–2 kt. (right half).

Flow through the mouth and valve chambers (Fig. 8) follows the channels "lateral" to the boss in clean and definite lines. Compression of the lines towards the outer surface of the channel, obvious at the faster rate, suggests that more water flows along this margin. At the higher rate, the lines leave the margin at a position preceding the valve and tend to straighten. The faring at the after end of the boss deflects the flow towards the valve where this occurs. Inside the boss, the main flow forms a distinct pattern near the spindle, but strong turbulence is evident beyond this. The main flow assists effectively in forcing the water from mouth and valve chambers into the valve opening. Even so, and largely because there is a sharp change of direction in flow from valve chamber into the valve, cavitation and turbulence are induced on the inner face of the valve. Therefore the valve may not be accepting water to its full capacity.

These tests demonstrate that the flow patterns in mouth and valve chambers are satisfactory, evidence which is of value in assessing whether this design is functioning adequately. It is regretted that higher rates of flow were not available for further tests.

Efficiency of the Catcher

Relative efficiencies between the catcher rigged with no net, with a net of 10 meshes/in., and with a net of 40 meshes/in., are shown in Figures 9 and 10. The catcher with each rig was towed over a straight course of one nautical mile (determined by radar). Each run was timed, and calculated speeds ranged between 3 and 9 knots. The flow meter was read at the beginning and end of each run.

Meter readings were highest when no net was enclosed—about 390 revolutions/mile (Fig. 9). The 10-mesh net caused a reduction to 345 revs./mile (about 11.5 per cent), and the 40-mesh net to 310 revs./mile (about 20.4 per cent). Thus, some restriction to flow is introduced with the nets. That this is due to frictional resistance offered to flow past the strands of the net, and not to insufficient filtering area, is suggested by two sources of evidence. When moderate blooms of diatoms are encountered the 40-mesh net clogs at first only in the lower 12 to 24 in., indicating that filtering is occurring over a relatively small area of the net. More convincing evidence is illustrated by Figure 9, where revolutions per mile of tow are plotted against speed of towing. It is apparent that over the range of speeds utilized there is no reduction in the number of revolutions, for each of the rigs investigated. This is an important point and shows that the quantity of water filtered per unit of distance is constant for each rig, although the volume presented per unit of time increases with the speed. If there were an insufficient area to filter the flow (or if there were other restrictions, the effects of which increased with speed), less water per unit of time would be accepted at the higher speeds and fewer revolutions recorded for a given distance.

An approximate calibration of the meter has been made for several speeds. It was towed mounted in a straight tube, 3 ft. long and 9 in. in diameter (the same diameter as the mouth and tail of the catcher). It is assumed the tube accepts all of the volume of water in a column with a cross-sectional area equal to the tube. The meter recorded

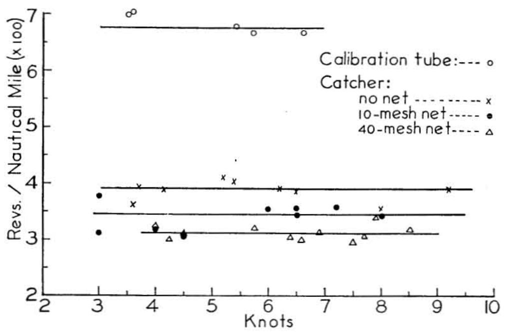


FIG. 9. Revolutions of the depth-flow meter per nautical mile plotted against speed of towing. The uppermost curve is from the readings obtained when towing a straight tube, 9 in. in diameter; the lower three curves result from towing the catcher with no net (upper), with a net of 10 meshes (middle), and a net of 40 meshes/inch (lower).

approximately 675 revolutions per nautical mile. Against this was the recording of 390 revs./nautical mile for the catcher (without a net). This represents an apparent acceptance value for the catcher of only 57.8 per cent (Fig. 10). Such a value suggests a major restriction to flow in the catcher, and it is probable that this is caused by the narrower orifice, namely the valve. This being so, the ideal acceptance would be in the ratio of $\frac{\text{area of valve}}{\text{area of mouth}}$, which is 0.649, i.e., the valve should accept 64.9 per cent of the water presented to the mouth. That the actual acceptance (57.8 per cent), by the valve is lower than its theoretical acceptance (64.9 per cent), indicates other, but less obvious, restrictions to flow. Cavitation on the inner face of the valve, and some details of the construction, are probably factors to be considered.

The volume of water in a column one nautical mile long (1.85 km.), of a diameter of 9 in. (22.9 cm.), is 76.7 m^3. The meter in the calibration tube recorded 675 revolutions for this volume, which is equivalent to 0.114 m^3/rev. The tail of the catcher is also a tube of 9 in. diameter, and it may be assumed the flow patterns in it are similar to those in the calibration tube. Therefore, a meter reading of 390 revs./mi. (no net in the catcher) represents an accepted volume of 390 times 0.114, i.e., 44.3 m^3. Ideally, the valve should accept 64.9 per cent of the volume presented to the mouth, i.e., of 76.7 m^3, which is 49.8 m^3. On this basis the valve accepts water with an efficiency of 89 per cent. Since frictional resistance is introduced by the nets the flow is reduced still further. For the net of 10 meshes per inch, the reduction is 11.5 per cent so that 39.2 m^3 is accepted (78.8 per cent efficient); for the 40-mesh net the volume is reduced by 20.4 per cent which is 35.2 m^3 (71 per cent efficient). (See Fig. 10, upper curve.)

These data demonstrate first, that the narrower aperture of the valve controls the flow of water into the catcher. Second, the nets introduce restrictions to flow, but as their filtering areas are adequate in relation to the area of the orifice controlling the flow, the restrictions do not change with speed, at least between 3 and 10 kt. Third, the catcher deals reasonably efficiently (89 per cent) with a

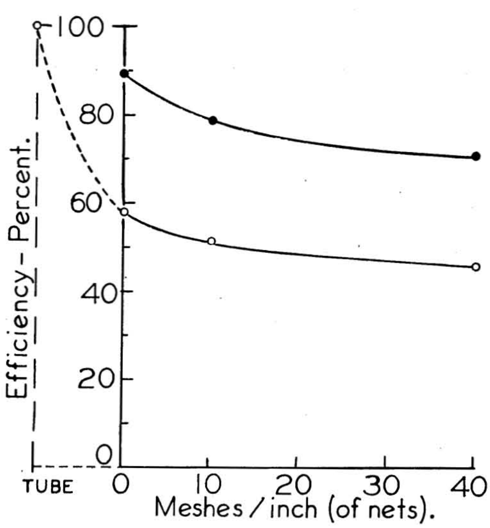


FIG. 10. Lower curve: percentage efficiencies of catcher with no net, and nets of 10 and 40 meshes/inch, relative to the calibration tube (of 9 in. diam.) when this is assumed to accept 100 per cent of the column of water presented to it. Upper curve: percentage efficiency of the catcher with no net (an absolute efficiency 89 per cent for a valve aperture of 7¼ in.), and with nets of 10 and 40 meshes per inch.

volume of water equivalent to unit length times the area of the valve.

Flow Through the Catcher

Flow through the body and tail of the catcher is controlled predominantly by the areas of their cross sections relative to that of the valve. The ratio between the areas of valve and body is 2.75, and between valve and tail, 1.55. If the rate of flow through the valve is assumed to equal the towing speed, then at 10 kt. the flow in the body is 3.65 kt. and in the tail, 6.5 kt. These rates assume an efficiency of 100 per cent by the valve; reduction of flow by the nets, and an efficiency value which is below 100 per cent, will lower them. The moderate rate in the body probably accounts for the undamaged condition of the plankton (see later).

There is probably an optimum rate of flow through the body (and the filter) for most efficient working of the unit. This becomes a factor in any new design which proposes a change in the diameter of the controlling orifice. Thus, an increase in the diameter of the valve to 9 in. (which, it may be assumed, will equalize the volume accepted by the valve and that presented to the mouth) will reduce the ratio between the cross-sectional areas of body and valve to 1.78. Rate of flow through the body would then be 5.6 kt. for a towing speed of 10 kt. Such a rate may damage organisms beyond an acceptable amount, or the frictional resistance of the nets may increase to a degree where it begins to seriously reduce the efficiency of the catcher. It is believed that the diameter of the valve can be increased, but this will probably require the diameter of the body to be increased also, so that flow does not exceed an acceptable speed, say of 4.5 kt. at a towing speed of 10 kt.

Plankton Catching

Trials of the ability of the catcher to collect plankton have proceeded to the extent that circumstances have permitted. It has not been possible to make repetitive hauls in one place or numerous series of hauls, in order to assess the versatility and reliability of the catching power of the unit. A conventional type of net, of 50 cm. diameter (Bary, 1956), was twice fished alternately in horizontal tows with the catcher, and other horizontal tows have been made with the latter. Some vertical tows with the catcher have been compared with collections from a Nansen-type closing net. Whenever a net has been included during trials with the unit, the bucket has been examined for plankton.

The range of organisms and the quantities collected are most encouraging. Several of the smaller species of pelagic fish, fish larvae, squid, and larger euphausiids and shrimp have been captured. Also, common forms such as copepods, chaetognaths, salps, and larval decapods are collected, sometimes in high numbers. When the catches of the 50-cm. net and the catcher were roughly equilibrated for differences in size of mesh, area of mouth, and distances towed, the catcher was believed to have collected a greater quantity of larger organisms, including fish and shrimp, than the net. Collections made during the vertical hauls with the 70-cm. Nansen-type of net and the catcher were similar in the range of organisms captured. Specimens are alive (except fish larvae) and quite undamaged at towing speeds up to 8 kt.

Although test hauls with the catcher are few, those made to date suggest it collects a representative range of organisms—a range which may be comparable with that taken by the 70-cm. Nansen closing net.

OPERATION

A "high-speed" plankton sampler, as well as being towed at fast rates, must also be quickly and easily handled on deck, recovered from, launched, and lowered to the level at which it is to be towed, and emptied of its catch.

On raising the present catcher from a horizontal tow, the depressor is lifted onto a hook attached to the ship's side (not necessary in calm water), and the rear end of the catcher is rested in the crotch on the guard rail (Fig. 6); the meter is read (or the smoked cylinder renewed), and tail and net are removed. A second net and frame can then be slipped into the body and the tail replaced. The unit is lifted over the side and while hanging free of the rail, the valve is opened. The depressor is then freed, and the whole is lowered into the water. For a team of three (one working the winch), the time taken on this routine is about two minutes. The ship may continue to steam at from 6 to 8 kt. The used net is washed down with sea water from a hose and the catch preserved; the net is then ready for the next tow.

To reach the required depth of a horizontal tow, the catcher is allowed to dive on an almost free-running winch, and a length of wire is veered equivalent to 2.5 times the depth (a ratio of approximately 1:2.5 was found to apply up to 100 m., but may not do so at greater depths. The depth-flow meter provides a check on the depth reached.) Meanwhile the ship may continue underway, altering speed to the towing speed, if necessary. At the end of the tow, the catcher is closed by messenger, recovered, and the usual routine followed.

In vertical tows with a single unit (no tows with multiple units have been made), the routine is similar. Additionally, the wire is released from the after bracket before the tail is lifted onto the rail, and is replaced again before lowering. The terminal sinker need not be lifted, but may require steadying with a strop or boat hook in rough weather.

Lowering for the vertical tow is rapid when compared with a Nansen-type of net. It is necessary to brake the winch to a vertical speed of about 4 kt. so that a strain is maintained on the wire, otherwise the catcher may dive nose first (see earlier). The haul is as rapid as the winch permits, or as is desirable. At depths below 750 m., delays of a minute or two are necessary, before commencing to haul, because of the falling time of the messenger. However, they do not greatly affect the very considerable saving of time accruing from the relatively rapid lowering, hauling, and recovery of the catcher from, and its return to, the water, during a series of vertical tows.

Before quantitative investigations can approach absolute values, as opposed to relative values, the efficiency and characteristics of the catching gear should be known. Currie and Foxton (1957) have provided pertinent data for their new quantitative (Nansen-type) net, but the equivalents do not seem to be available for high-speed samplers. The meter for such a sampler requires calibrating for flow, but in a situation remote from influences of the gear which may interfere with its functioning (e.g., in a calibration tube), and over the speeds at which the sampler is likely to be used. Values obtained must be considered in relation to the flow through the sampler itself, with and without nets included, and again over the relevant range of speeds. The proportion of the column of water (of unit length and of a cross-section equal to that of the controlling orifice) accepted by the gear under conditions of differing rigs and speeds now can be estimated fairly accurately. That is, the efficiency of the catcher can be determined. The optimum towing speed can now be established, together with the effects on flow of nets of differing meshes, or of clogging. With these data, one may reasonably study whether the catcher is collecting a representative sample of the organisms it encounters, and thus make an appreciation of the true density of the plankton population being investigated.

SUMMARY

A plankton catcher is described which has been towed successfully at speeds up to 10 kt. horizontally, and 5 to 6 kt. vertically. It can be closed during either tow. To convert from the rigging for one type of tow, to that for the other, is rapid and easy and is believed not to alter the catching ability of the unit.

A depth-flow meter is included in the catcher. It has been calibrated by towing first when mounted in a tube of equal diameter to the mouth of the catcher (9 in.), and second, in the catcher, at speeds between 3 and 9 kt. The catcher was towed without a net included, and successively with nets of 10 and 40 meshes to the inch. Data from these tests show that the valve of the closing mechanism (7¼ in. diameter) controls the flow into the catcher; about 89 per cent of the water presented to the valve is accepted. A net of 10 meshes per inch further reduces flow by 11.5 per cent, and one of 40 meshes by 20.4 per cent. Frictional resistance to flow, offered by the meshes, is believed to be responsible as the filtering area of either net is more than adequate to filter the quantity of water presented, at speeds to 10 knots.

Plankton is mostly alive and undamaged. Indications are that a representative range of organisms is being captured, including small squid and pelagic fish and the larger pelagic crustacea.

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REFERENCES

ARNOLD, E. L. 1952. A high-speed plankton sampler (Model Gulf IA). *U. S. Dept. Int. Fish & Wildlife Serv., Spec. Sci. Rpt., Fisheries* 88: 1–6.

BARNES, H. 1953. A simple and inexpensive closing net. *Dell 'Inst. Italiano di Idrobiol. Dott. Marcode Marchi, Mem.* 7: 189–198.

BARNES, H., and S. M. MARSHALL. 1951. On the variability of replicate plankton samples and some applications of 'contagious' series to the statistical distribution of catches over restricted periods. *Jour. Mar. Biol. Assoc. U. K.* 30: 233–263.

BARY, B. M. 1956. Notes on ecology, systematics and development of some Mysidacea and Euphausiacea (Crustacea) from New Zealand. *Pacific Sci.* 10(4): 431–467.

CASSIE, R. M. 1956. The spawning of the snapper *Chrysophrys auratus* Forster, in the Hauraki Gulf. *Roy. Soc. New Zeal. Trans. and Proc.* 84(2): 309–328.

CLARKE, G. L., and D. F. BUMPUS. 1940. The plankton sampler—an instrument for quantitative plankton investigations. *Amer. Limnolog. Soc., Spec. Pub.* 5: 1–8.

CURRIE, R. I., and P. FOXTON. 1957. A new quantitative plankton net. *Jour. Mar. Biol. Assoc. U. K.* 36: 17–32.

GEHRINGER, J. W. 1952. An all-metal plankton sampler. *U. S. Dept. Int. Fish & Wildlife Serv., Spec. Sci. Rpt., Fisheries* 88: 7–12.

HARDY, A. C. 1935. The continuous plankton recorder. A new method of survey. *Cons. Perm. Internatl. pour l'Explor. de la Mer., Rap. Procès-Verb. des Réunions* 95: 36–47.

HART, E. G. 1935. Some devices for the manipulation of marine plankton collections on board ship. *Jour. du Cons. pour l'Explor. Mer* 10(2): 173–178.

HARVEY, H. W. 1934. Measurements of phytoplankton population. *Jour. Mar. Biol. Assoc. U. K.* 19: 761–774.

KEMP, S., A. C. HARDY, and N. A. MACKINTOSH. 1929. Discovery Investigations: objects, equipment and methods. *Discovery Rpt.* 1: 141–232. Cambridge University Press, London. Issued by Discovery Committee, London, and now by National Institute of Oceanography, Wormley, Surrey.

MARR, J. W. S. 1938. On the operation of large plankton nets. *Discovery Rpt.* 18: 105–120. Cambridge University Press, London. Issued by Discovery Committee, London, and now by National Institute of Oceanography, Wormley, Surrey.

MOTODA, SIGERU. 1952. New plankton samplers. *Bul. Faculty of Fisheries, Hokkaido Univ.* 3(3): 181–186.

SHEARD, K. 1941. Improved methods of collecting marine organisms. *Rec. South Austral. Mus.* 7(1): 11–14.

SVERDRUP, H. U., M. W. JOHNSON, and R. H. FLEMING. 1942. *The Oceans, Their Physics, Chemistry and General Biology*. Prentice Hall, New York.

WINSOR, C. P., and L. A. WALFORD. 1936. Sampling variations in the use of plankton nets. *Jour. du Cons. pour l'Explor. Mer* 11: 190–204.

WINSOR, C. P., and G. L. CLARKE. 1940. A statistical study of variation in the catch of plankton nets. *Sears Found., Jour. Mar. Res.* 2(1): 1–34.